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Abstract

It has been well established that polar orbiting satellites can see mild to severe charging levels during solar minimum conditions (Frooninckx and Sojka, 1992, Anderson and Koons, 1996, Anderson, 2012). However, spacecraft operations during solar maximum cannot be considered safe from auroral charging. Recently, we have seen examples of high level charging during the recent approach to solar maximum. We present here a survey of charging events seen by the Defense Meteorological Satellite Program (DMSP) satellites (F16, F17) during the solstices of 2011 and 2012. In this survey, we summarize the condition necessary for charging to occur in this environment, we describe how the lower than normal maximum conditions are conducive to the environment conditions necessary for charging in the polar orbit, and we show examples of the more extreme charging events, sometimes exceeding 1 kV, during this time period. We also show examples of other interesting phenomenological events seen in the DMSP data, but which are not considered surface charging events, and discuss the differences.

Conditions Needed for Auroral Charging

1. Satellite is in darkness
2. An intense, energetic electron (> 14 keV population) precipitation event is required (flux > 10⁸ electrons cm⁻² s⁻¹ sr⁻¹)
3. Locally depleted (< 10⁴ cm⁻³) ambient plasma density

Surface Charging Physics

Surface charging is the result of a current balance on the surface of a spacecraft. Charging is described by the time dependent current balance relation

$$\frac{dQ}{dt} = \frac{d\sigma}{dt} A = C \frac{dV}{dt} = \sum_k I_k \approx 0 \text{ (at equilibrium)}$$

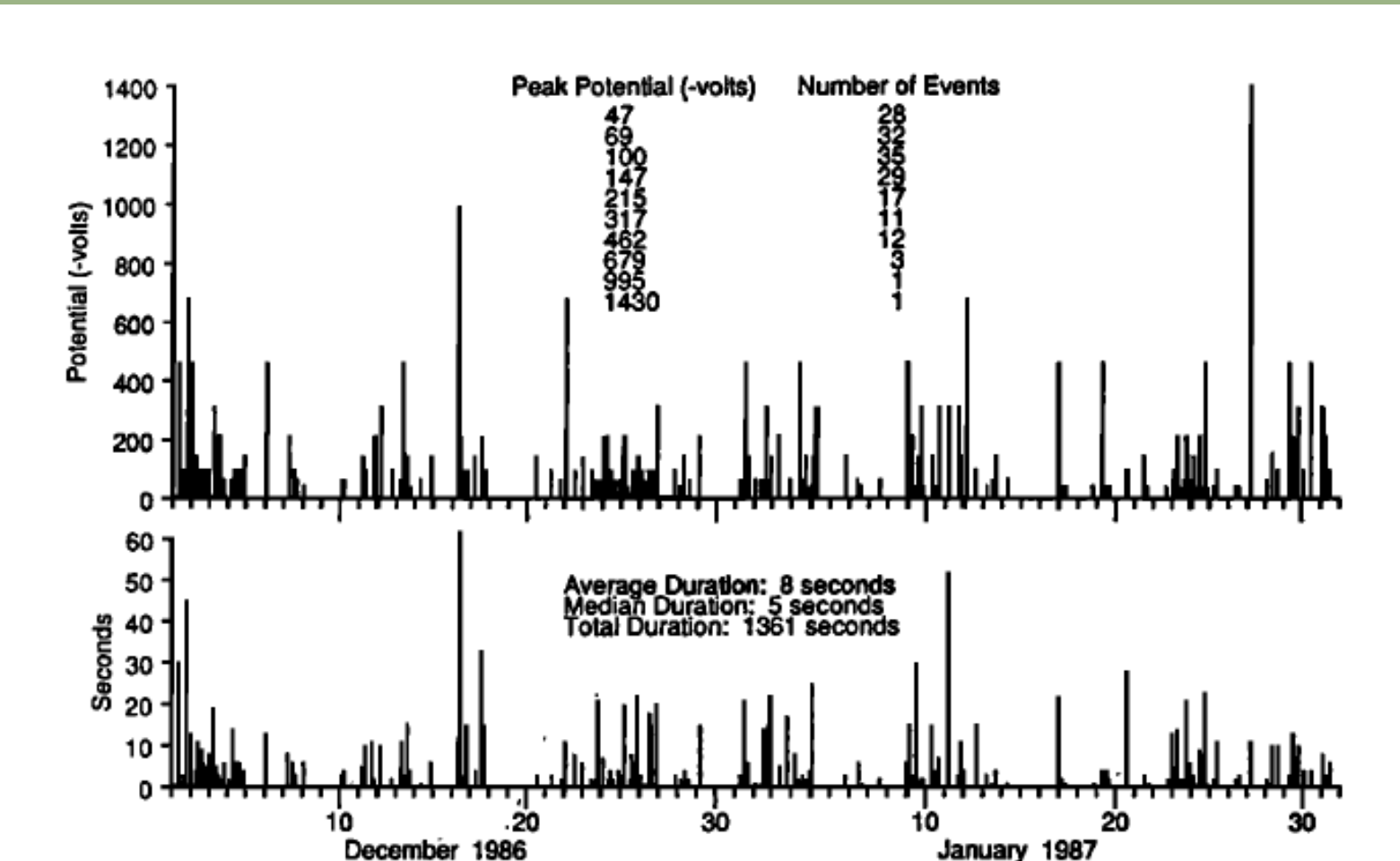
where Q is the total charge and σ the surface charge accumulating on the surface area A, C is the capacitance of the area A, and V the voltage of the surface. The currents of importance to surface charging are: *Incident ions, incident electrons, backscattered electrons, conduction currents, secondary electrons, photoelectrons, and active current sources (beams, thrusters).*

Auroral charging is readily identified from the “ion line” signature that appears in ion electrostatic analyzer records. The ion line is the result of ambient low energy ions accelerated by the spacecraft potential from an initial energy $E_0 \sim 0$ eV to a final energy $E = E_0 + q\phi$ eV where q is the charge of the ion and ϕ the spacecraft surface potential in volts.

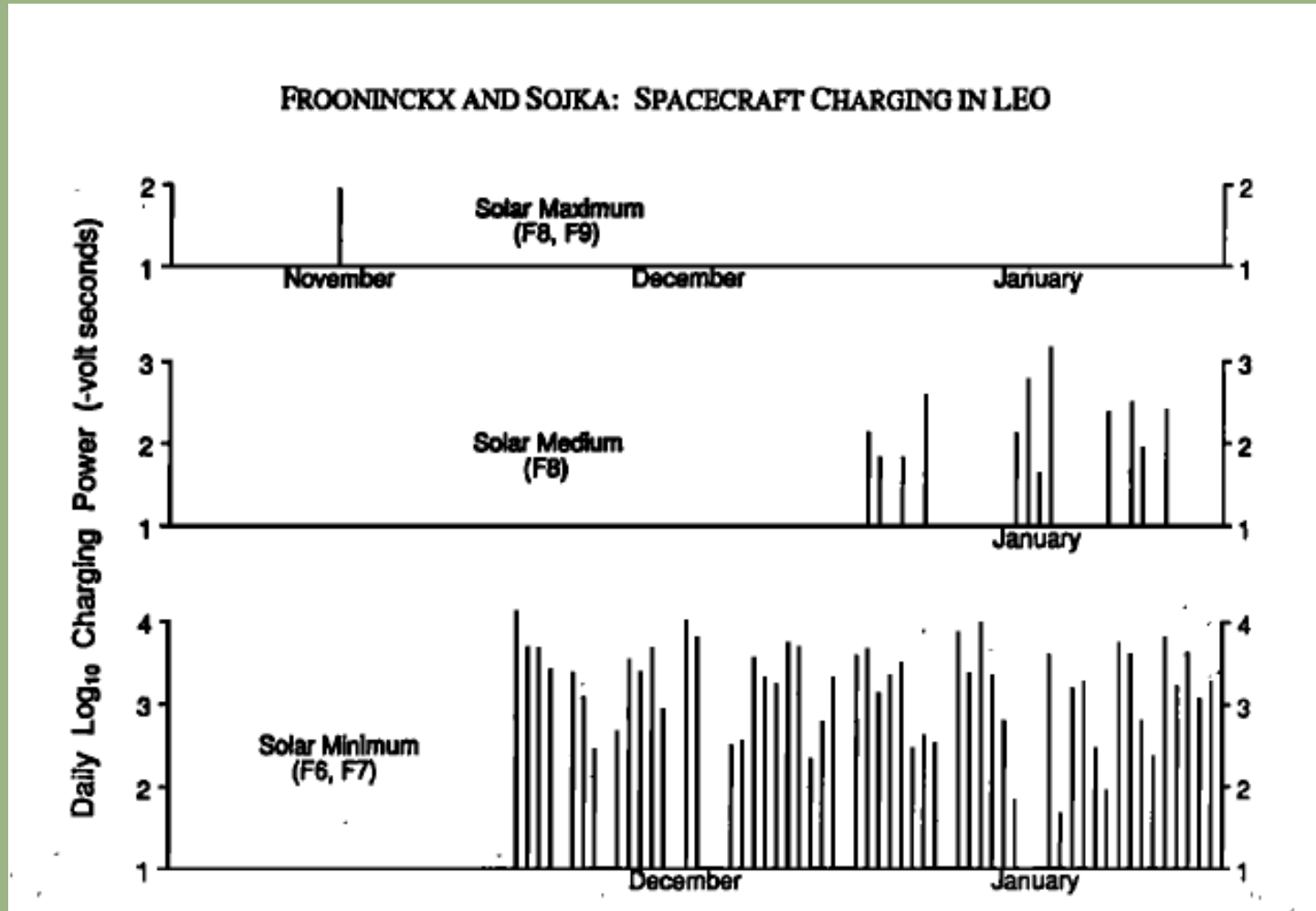
Event Criteria

1. At least 3 seconds
2. At least -30 V peak
3. Distinguishable ion line, no underlying structure

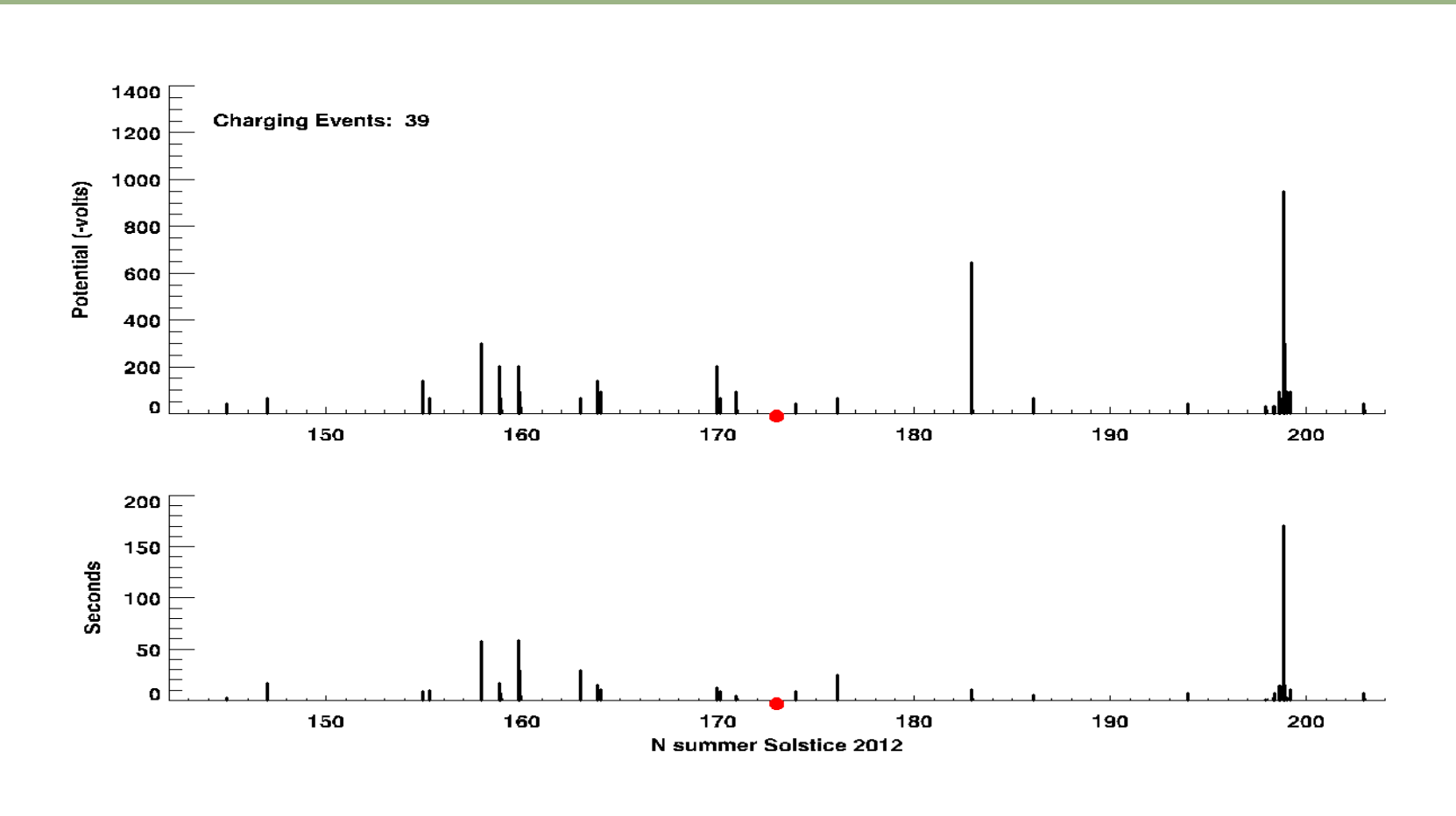
Frequency and Distribution of Auroral Charging



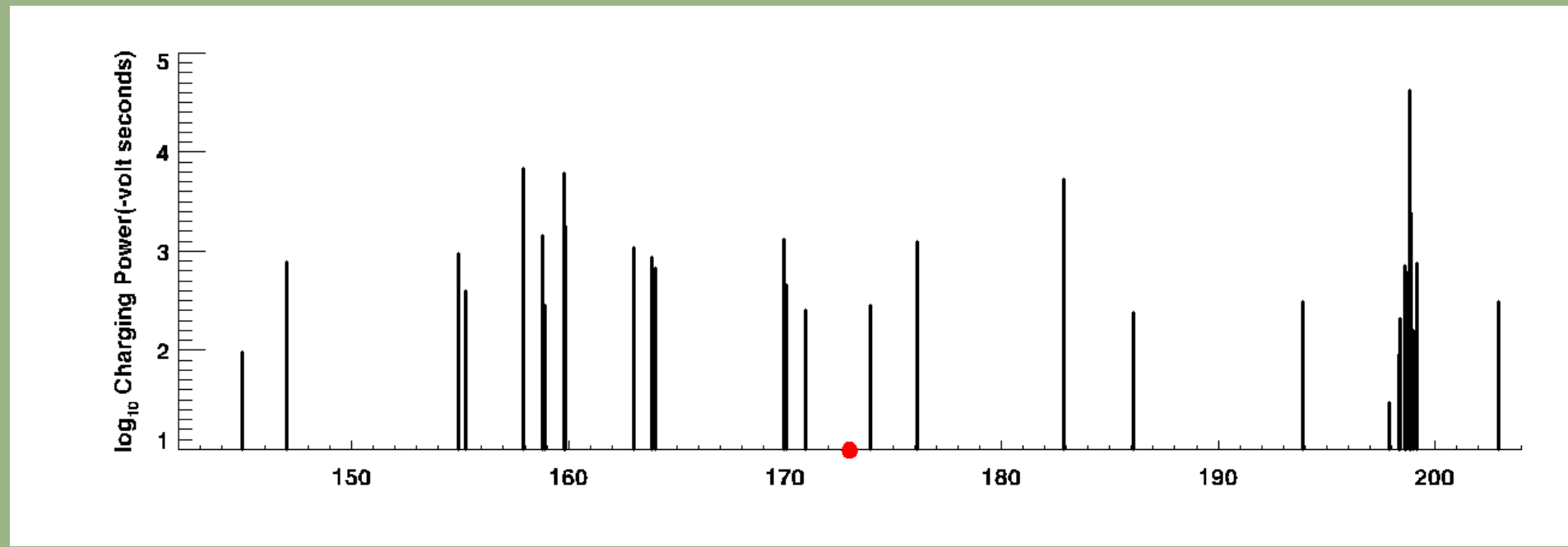
(a) DMSP Charging Frequency December 1986 – January 1987



(b) Distribution of DMSP and Freja Charging Events



(c) DMSP Charging Frequency May 21 – July 21, 2012

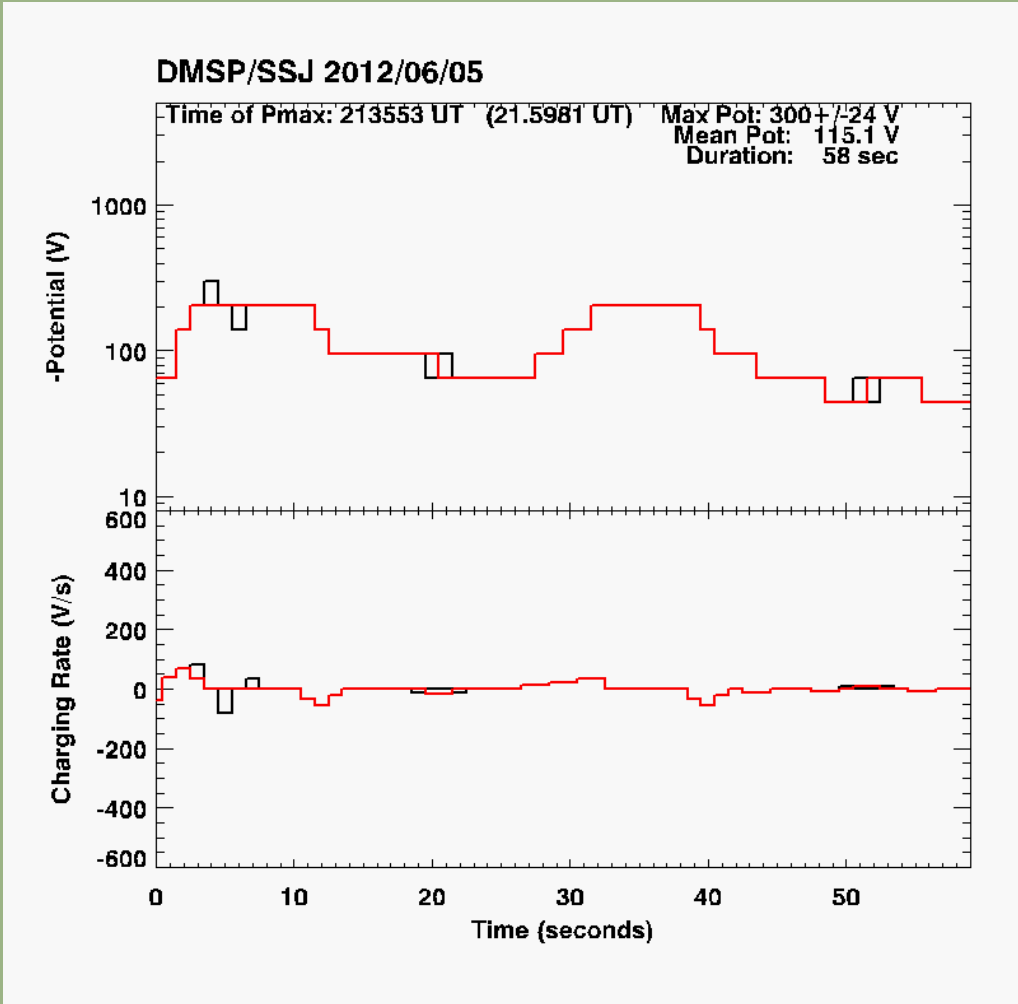
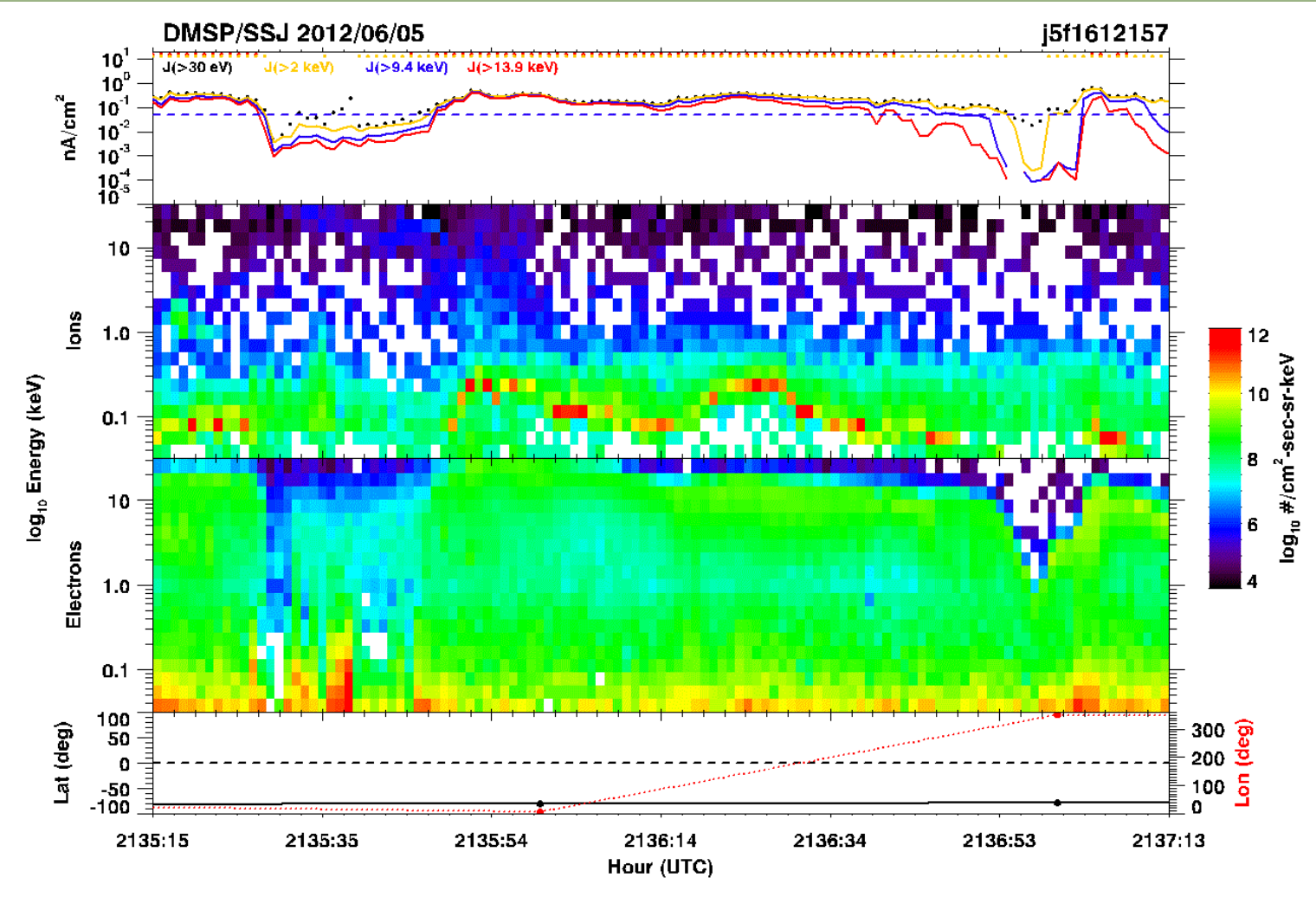


(d) DMSP Charging Power May 21 – July 21, 2012

Figures (a) and (c) are the maximum charging potential (top panel) and charging duration (lower panel). Figures (b) and (d) are the charging power for each event. Figures (a) and (b) are from Frooninckx, T.B., and J.J. Sojka, 1992.

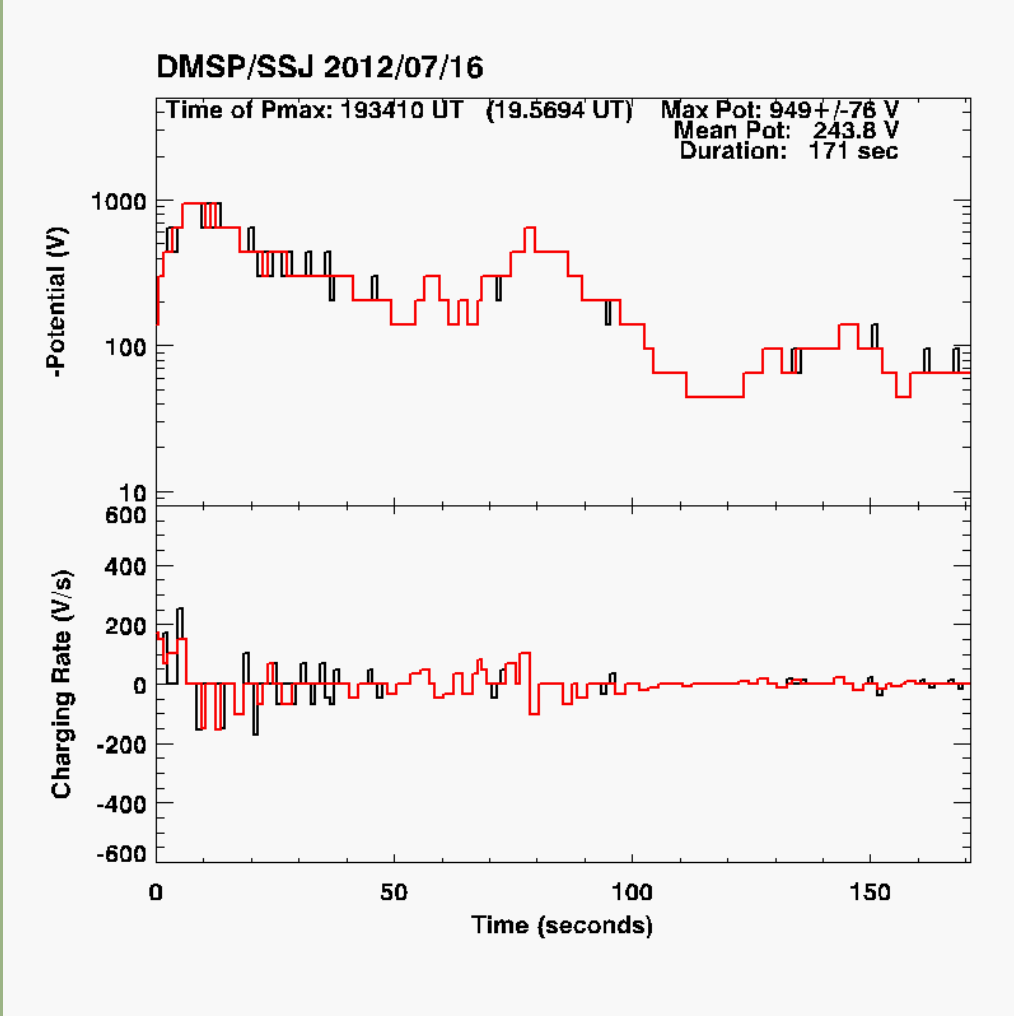
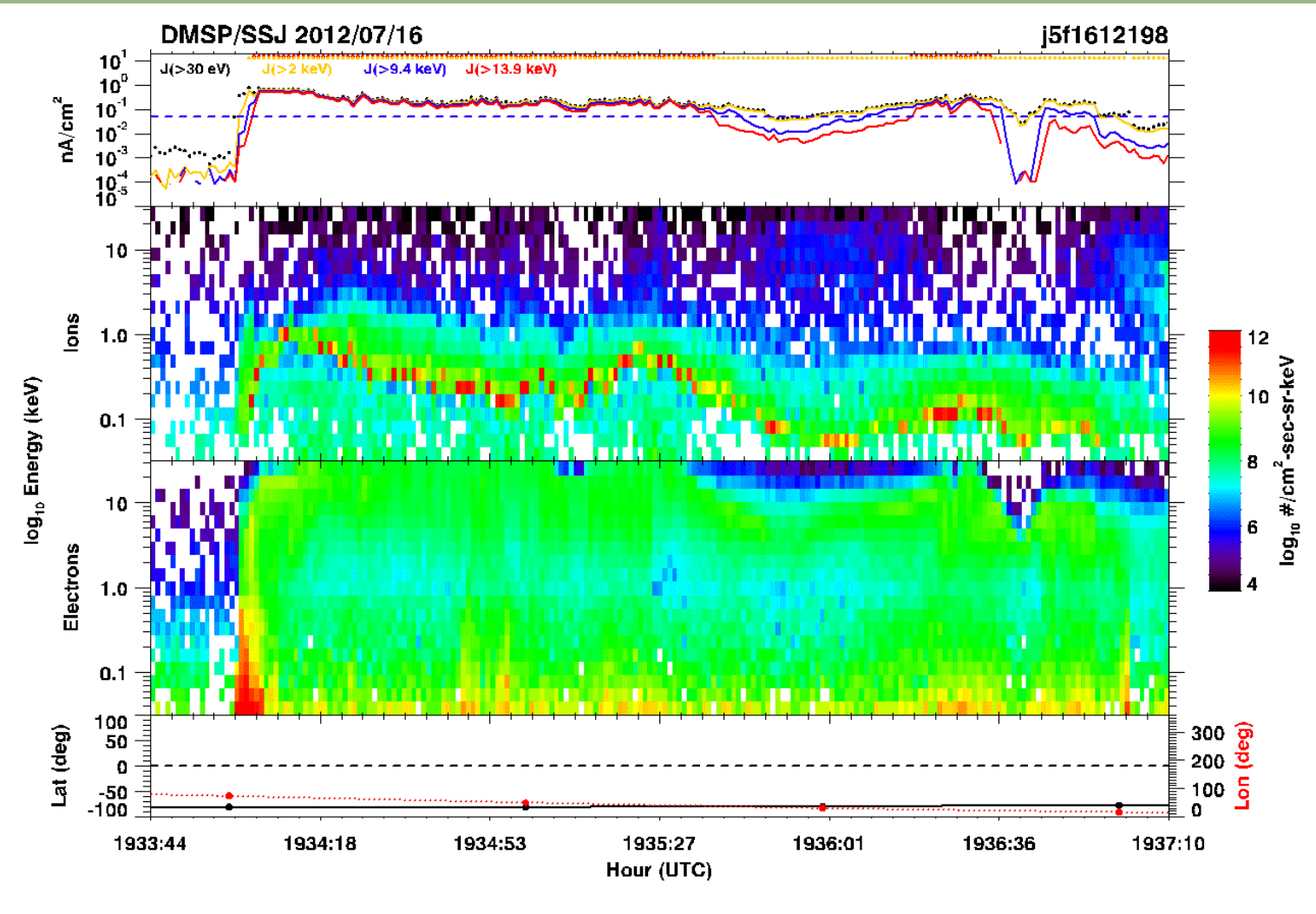
Auroral charging is most common during solar minimum conditions and most commonly encountered in the midnight sector of the auroral oval (Frooninckx and Sojka, 1992; Anderson 2000, 2001; Wahlund et al. 1999; Ericksson and Wahlund, 2005). However, we find that during the current near solar maximum conditions of Solar Cycle 24, with sufficiently low ambient plasma density, there can still be auroral charging events.

Event 1: DMSP F16



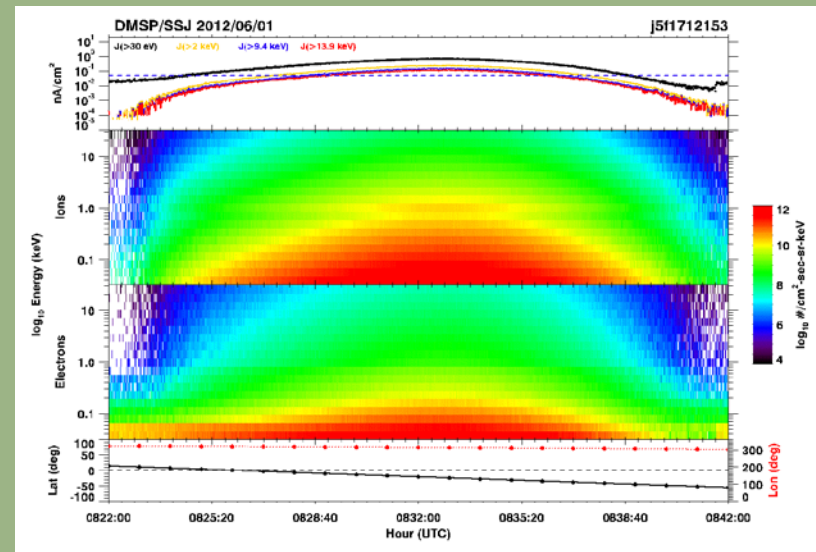
```
#-----DMSP Charging Event-----
# DMSP_CE_f16_2012-06-05_213553_300.txt
# Satellite: f16
# Date: 2012/06/05
# Data file: JSF1612157
#
# Max V: 300 +/- 24 Volts
# Mean V: 115.1 Volts
# Time Max V: 213553 UT (21.5981 UT)
# Duration: 58 sec
#
# Time (sec) > V summary:
# > 4 kV: 0 sec
# > 3 kV: 0
# > 2 kV: 0
# > 1 kV: 0
# > 900 V: 0
# > 600 V: 0
# > 400 V: 0
# > 300 V: 0
# > 200 V: 16
# > 100 V: 22
# > 40 V: 60
#
# UT Hr Seconds Pot (V) Rate (V/s)
#-----
21.5969 0.0 65 -36.78
21.5972 1.0 65 36.78
21.5975 2.0 139 69.33
21.5978 3.0 204 80.68
*lines deleted*
```

Event 2: DMSP F16

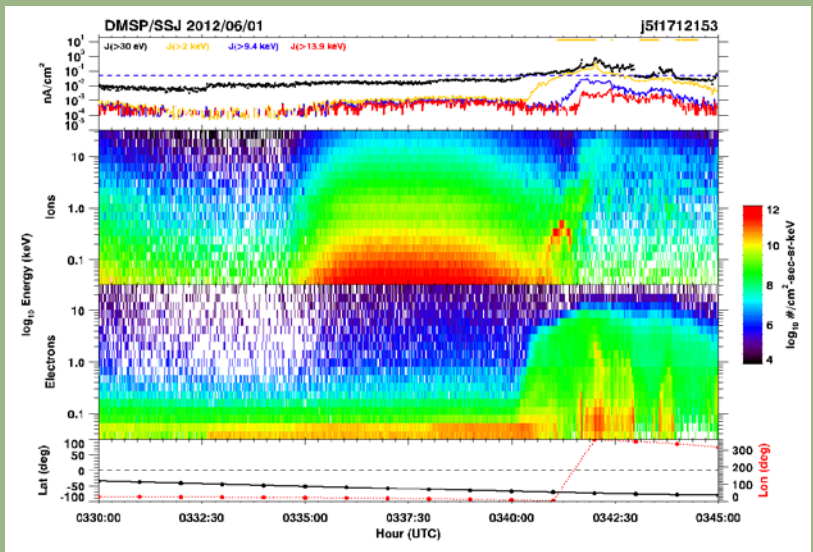


```
#-----DMSP Charging Event-----
# DMSP_CE_f16_2012-07-16_193410_949.txt
# Satellite: f16
# Date: 2012/07/16
# Data file: JSF1612198
#
# Max V: 949 +/- 76 Volts
# Mean V: 243.8 Volts
# Time Max V: 193410 UT (19.5694 UT)
# Duration: 171 sec
#
# Time (sec) > V summary:
# > 4 kV: 0 sec
# > 3 kV: 0
# > 2 kV: 0
# > 1 kV: 0
# > 900 V: 6
# > 600 V: 17
# > 400 V: 38
# > 300 V: 38
# > 200 V: 87
# > 100 V: 108
# > 40 V: 172
#
# UT Hr Seconds Pot (V) Rate (V/s)
#-----
19.5678 0.0 139 170.62
19.5681 1.0 300 150.57
19.5683 2.0 440 172.94
19.5686 3.0 646 0.00
*lines deleted*
```

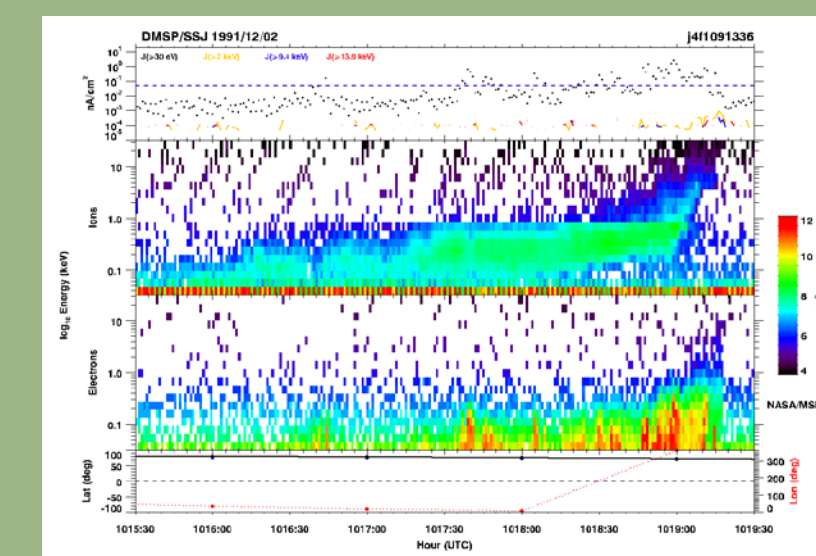
Other Phenomenon



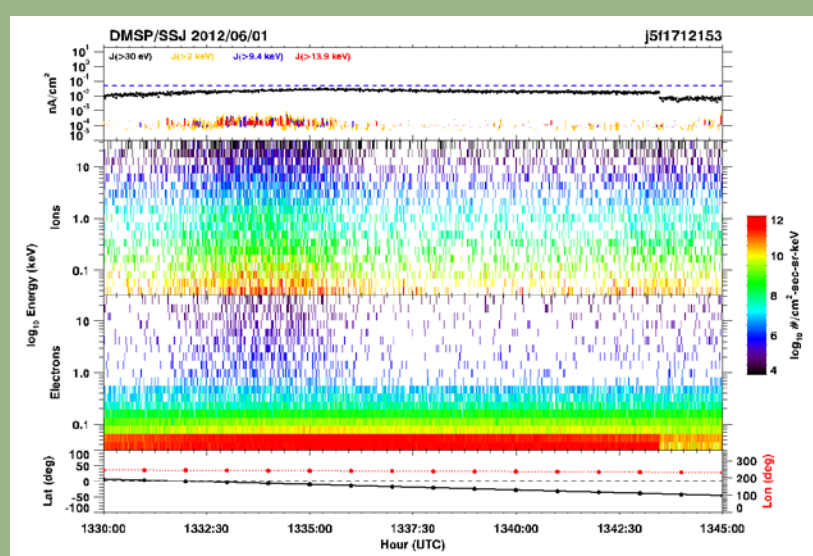
South Atlantic Anomaly



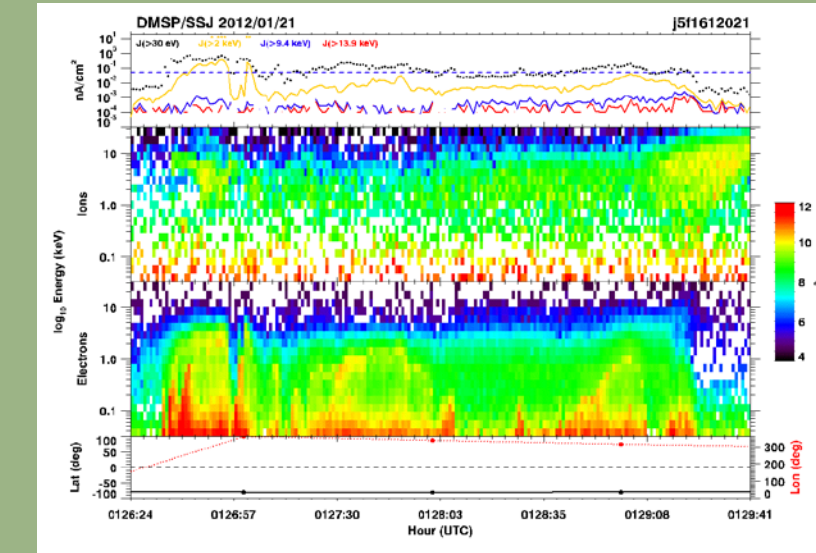
Outer Radiation Belt



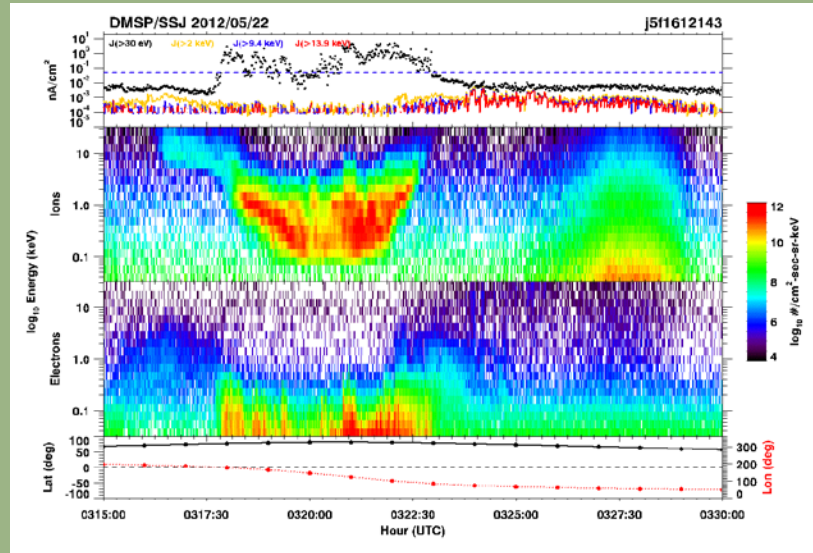
Ion Cusp / Solar Array Charging



Photoemission



Inverted V



Butterfly – Auroral Oval

Acknowledgements

DMSP SSJ/4 and SSJ/5 electrostatic analyzer records were obtained from the NOAA National Geophysical Data Center (NGDC). We thank Dr. William Denig for providing his SSJ analysis software which forms the basis of the charging analysis tool.

References

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Discussion and Summary

The examples shown here are the result of an initial effort to characterize extreme auroral charging events. These events are encountered infrequently by spacecraft in polar low Earth orbit but are the kind of event that drive spacecraft design. We have focused on the extreme potentials, duration the potentials exceed a threshold value, and mean potentials because the information is needed by spacecraft designers for evaluating the response of the spacecraft to the charging environment. Generally, auroral charging events are seen predominantly during solar minimum conditions. However, we have seen charging events of nearly -1000 V during the approach to solar maximum conditions due to the lower than average solar activity in Solar Cycle 24. We focus this study on the solstices (May - July, 2012 and Nov, 2011 - Jan, 2012) because of the larger likelihood of encountering charging events.

- Temporal variations of the spacecraft potential through a charging event are important since extreme potentials are generally only a subset of the charging event,
- Frame potentials may reach kilovolt levels in auroral charging environments, but the duration of charging at these most extreme levels are limited to periods of a few seconds to perhaps ten to fifteen seconds,
- Mean potentials over the period of a charging event never exceed a few hundred volts, and
- Rise time of the spacecraft potential is generally rapid for the events, with a slower time to decrease back to equilibrium.

Future work is planned to extend the study to a wider range of charging events to more fully characterize the auroral charging environment for this solar maximum period. A paper to Geophysical Research Letters is in work.

| Date | Time (UT) | Φmax (volts) | <Φ> (volts) |
|-----------|-----------|--------------|-------------|
| 23-May-12 | 22.6881 | 44+-4 | 33.5 |
| 25-May-12 | 23.9258 | 65+-5 | 45.2 |
| 2-Jun-12 | 22.225 | 139+-11 | 101.5 |
| 2-Jun-12 | 22.235 | 95+-8 | 58.4 |
| 3-Jun-12 | 6.7517 | 65+-5 | 39.5 |
| 5-Jun-12 | 21.5981 | 300 +/- 24 | 115.1 |
| 6-Jun-12 | 19.7069 | 204+-16 | 81.9 |
| 6-Jun-12 | 21.3517 | 44+-4 | 39.3 |
| 6-Jun-12 | 21.3972 | 65+-5 | 44 |
| 7-Jun-12 | 19.4814 | 204+-16 | 102.4 |
| 7-Jun-12 | 21.1367 | 95+-8 | 60 |
| 10-Jun-12 | 23.8917 | 65+-5 | 37.7 |
| 11-Jun-12 | 20.305 | 139+-11 | 86.2 |
| 11-Jun-12 | 20.3161 | 65+-5 | 48 |
| 11-Jun-12 | 20.3253 | 65+-5 | 57.1 |
| 11-Jun-12 | 20.3342 | 65+-5 | 50.1 |
| 11-Jun-12 | 23.7486 | 95+-8 | 60.1 |
| 17-Jun-12 | 22.4333 | 204+-16 | 101 |
| 17-Jun-12 | 22.4569 | 65+-5 | 42.3 |

| Date | Time (UT) | Φmax (volts) | <Φ> (volts) |
|-----------|-----------|--------------|-------------|
| 18-Jun-12 | 1.7456 | 65+-5 | 50.3 |
| 18-Jun-12 | 22.1944 | 95+-8 | 61 |
| 21-Jun-12 | 23.2086 | 44+-4 | 31.3 |
| 24-Jun-12 | 2.2047 | 65+-5 | 49.4 |
| 30-Jun-12 | 21.3475 | 646+-52 | 451.7 |
| 4-Jul-12 | 1.7736 | 65+-5 | 47 |
| 11-Jul-12 | 22.3686 | 44+-4 | 44 |
| 15-Jul-12 | 21.5672 | 30+-2 | 30 |
| 16-Jul-12 | 7.8097 | 30+-2 | 30 |
| 16-Jul-12 | 9.5275 | 30+-2 | 30 |
| 16-Jul-12 | 14.585 | 95+-8 | 51.1 |
| 16-Jul-12 | 14.5931 | 95+-8 | 71.9 |
| 16-Jul-12 | 19.5694 | 949+-76 | 243.8 |
| 16-Jul-12 | 21.2844 | 95+-8 | 67.3 |
| 16-Jul-12 | 21.2903 | 300+-24 | 147.6 |
| 17-Jul-12 | 0.5656 | 95+-8 | 57 |
| 17-Jul-12 | 4.1678 | 95+-8 | 66.4 |
| 20-Jul-12 | 22.1242 | 44+-4 | 44 |